AMENDMENTS TO THE SPECIFICATION

Please replace the paragraph at page 1, lines 9-17 of the Specification with the following amended paragraph:

As is known in the art, electrical signals may be conveyed by a number of transmission mediums, including electrical traces on circuit boards (*e.g.*, transmission lines), waveguides, and free-space. In many applications, one or more electrical signals are converted from one transmission medium to another. Structures which convert signals from one medium to another are called coupling structures. Such structures for coupling from circuit board traces to waveguides have become increasingly popular due to their growing applications in the area of ~~low cost packages~~ low-cost packages for monolithic microwave integrated circuits (MMICs), particularly for MMICs which process signals in the millimeter-wave frequency bands.

Please replace the paragraph at page 1, lines 18-27 of the Specification with the following amended paragraph:

In most of the prior art circuit-board to waveguide coupling structures, a metal cavity or a metal short on a different plane is used to achieve impedance matching to the waveguide and to avoid back scattering from the waveguide. In some cases, the distance of the back metal short from the planar circuit sets the frequency of operation, which is not always desirable. Instead of using a back metal short, other prior art structures use a quarter-wavelength long dielectric slab inserted into the waveguide to achieve better impedance matching. Such a dielectric slab can have a metal patch disposed on one of its surfaces, or it may be left blank. For these dielectric-slab embodiments, package costs ~~becomes~~ become quite high due to the difficulties in the mechanical fitting and alignment of the dielectric slab inside the waveguide wall.

Please replace the paragraph at page 3, lines 21-22 of the Specification with the following amended paragraph:

It is another object of the present invention to provide such [[a]] coupling structures which are compact in size and which can be easily coupled to a waveguide.

Please add the following paragraph at page 4, line 19 of the Specification:

FIG. 8 is a partial cross-sectional view showing where the patch antenna, capacitive diaphragm, and feed trace are disposed within the substrate according to the present invention.

Please replace the paragraph at page 4, line 22 through to page 5, line 5 of the Specification with the following amended paragraph:

FIG. 1 shows a perspective view of an exemplary coupling structure 20 formed on a substrate layer 1 according to the present invention. Substrate layer 1 may comprise a single sub-layer of material, which is usually a dielectric material, or may comprise a plurality of sub-layers of dielectric material and patterned sub-layers of conductive material. To simplify the presentation of the present invention, a single dielectric sub-layer for substrate layer 1 is shown in <u>FIGS. 1-5</u> ~~the figures~~. Coupling structure 20 is adapted to be coupled to a waveguide 10 at a first end 11 of waveguide 10, as shown by the dashed <u>attachment</u> lines 50 in the figure. Waveguide 10 also has a second end 12 and a housing 14 disposed between first end 11 and second end 12. Housing 14 has one or more walls 16, and defines a longitudinal dimension 15 between first end 11 and second end 12 along which electromagnetic waves may propagate. Four walls are shown in this exemplary embodiment, but a different number may be used, such as one wall for cylindrical waveguides and conical waveguides, and such as twelve walls for ridge waveguides. In all cases, the one or more walls 16 form a lip 18 at first end 11 to which coupling structure 20 may be attached, as described below.

Please replace the paragraph at page 5, line 22 through to page 6, line 8 of the Specification with the following amended paragraph:

Coupling structure 20 further comprises a patch antenna 24 disposed on bottom major surface 2 or within the substrate layer (as may be the case when the substrate layer comprises sub-layers), and further located within first area 21. Patch antenna 24 is physically separated, and conductively isolated, from ground ring 22. In its most basic form, patch antenna 24 comprises a pad of an electrically conductive material, and may

comprise the same conductive material as ground ring 22. Patch antenna preferably comprises the shape of a rectangle which has a width W along the longer cross-sectional dimension of the waveguide and a length L along the shorter cross-sectional dimension of the waveguide. However, other shapes are possible, and the dimensions thereof may be determined through the use of a three-dimensional (3-D) ~~(3d)~~ electromagnetic wave simulation program, such as many of the simulation products available from Ansoft Corporation, Bay Technology, Sonnet Software, Inc., and similar companies. In the present simulation, the High Frequency Structure Simulator software initially manufactured by Hewlett-Packard and subsequently by Agilent Technologies (and now sold by Ansoft Corporation) has been used. As described below in greater detail, the electrical signal which is to be coupled to the waveguide is electrically coupled to patch antenna 24, which in turn excites the desired propagation modes within the waveguide (which are usually TE_{mn} modes).

Please replace the paragraph at page 6, lines 27-29 of the Specification with the following amended paragraph:

In preferred practice of the present invention, a ground plane 34 is included on bottom major surface 2 of substrate layer 1 to aid in constructing impedance-controlled transmission lines on top major surface 3. As described below in greater detail, preferred embodiments may also include conductive vias 29 for electrically coupling capacitive diaphragm 28 to a ground plane (not shown in FIG. 1) that is hidden behind the diaphragm, and may include conductive vias 39 for electrically coupling ground plane 34 to other ground planes (not shown in FIG. 1) that are hidden behind ground plane 34.

Please replace the paragraph at page 6, line 30 through to page 7, line 6 of the Specification with the following amended paragraph:

FIG. 2 shows the same perspective view of FIG. 1, but with substrate layer 1 and exemplary coupling structure 20 rotated and moved down to make contact with the first end 11 (not depicted in FIG. 2) of waveguide 10. In this configuration, the lip 18 of waveguide 10 fits onto ground ring 22 (not depicted in FIG. 2), which preferably has a shape which is substantially a mirror image of the shape of lip 18, but preferably with a

wider ~~wide~~ width. Lip 18 may be adhered to ground ring 22 with solder, electrically conductive adhesive, or a metal diffusion bond or the like. Preferably, all of the walls 16 of the waveguide are electrically coupled to ground ring 22 at lip 18. <u>Housing 14 and second end 12 of waveguide 10, which were previously described with respect to FIG. 1, are shown by the same reference numbers in FIG. 2.</u>

Please replace the paragraph at page 7, lines 7-19 of the Specification with the following amended paragraph:

The basic construction of coupling structure 20 further comprises a ground plane 26 disposed on top major surface 3 and over an area of surface 3 which is opposite to at least first area 21. In its most basic form, ground plane 26 comprises a layer of conductive material disposed within this area. In preferred embodiments of coupling structure 20, ground plane 26 is further disposed over an area of surface 3 which overlies ground ring 22. Ground plane 26 aids in the operation of patch antenna 24 by providing the antenna with an opposing grounding surface, and further reduces transmission (*e.g.*, back scattering) of electromagnetic waves from first end 11 of waveguide 10 by providing a conductive shield. When capacitive diaphragm 28 <u>(see FIG. 1)</u> is employed, it is preferably coupled to ground plane 26 by one or more conductive vias 29 formed in or through substrate layer 1 and between its major surfaces 2 and 3. The positions of vias 29 are outlined by dashed lines in FIGS. 1 and 2, and an exemplary one is shown in cross-sectional view by FIG. 3. <u>As seen in FIG. 3, ground plane 26 and capacitive diaphragm 28 are disposed on opposite surfaces of substrate 1, and via 29 is disposed through substrate 1 and between ground plane 26 and capacitive diaphragm 28. As described below in greater detail, FIG. 3 also shows the same structure for a via 39 coupled between ground plane 34 and another ground plane 36, with ground planes 34 and 36 being disposed on the opposite surface of substrate 1, and with the reference numbers 34, 36, and 39 shown within parentheses.</u>

Please replace the paragraph at page 7, line 20 through to page 8, line 2 of the Specification with the following amended paragraph:

As thus far described, the basic construction of coupling structure 20 comprises ground ring 22, first area 21, patch antenna 24, and ground plane 26, and covers the portion of substrate layer 1 which is spanned by ground ring 22. Further embodiments of coupling structure 20 comprise capacitive diaphragm 28 if an improvement in electromagnetic impedance matching is desired or needed. The portion of substrate layer 1 not covered by these components may be configured by the particular application which utilizes the present invention. In ~~FIG. 1~~ <u>FIG. 2</u>, we have shown the exemplary application of a monolithic microwave integrated circuit (MMIC) 8 which utilizes coupling structure 20 to couple its electrical signal 4 to waveguide 10. MMIC 8 is fed with power, ground, and a plurality of low-frequency signals by a plurality of electrical traces 6 disposed on top major surface 3 of substrate layer 1. Traces 6 are coupled to a plurality of pads disposed on a surface of MMIC 8 by way of a plurality of pads ~~6~~ <u>5</u> disposed on surface 3 of substrate layer 1 and by the way of solder bumps 7 disposed between pads 6 and the corresponding pads on MMIC 8.

Please replace the paragraph at page 8, lines 3-28 of the Specification with the following amended paragraph:

Because of the perspective angle used in FIG. 2, the output pad on MMIC 8 for signal 4 cannot be directly seen, but is shown in outline by dashed lines in FIG. 2. The pad for signal 4 is coupled to a high-frequency trace 30 by a respective solder bump 7. Trace 30 conveys electrical signal 4 to coupling structure 20, where it is coupled to patch antenna 24 by way of a conductive via 32. The position of via 32 is outlined by dashed lines in FIGS. 1 and 2, and is shown in cross-sectional view by FIG. 4. <u>FIG. 4 shows ground plane 26 and electrical trace 30 disposed on the top major surface of substrate 1; shows patch antenna 24, capacitive diaphragm 28, ground ring 22, and ground plane 34 disposed on the bottom major surface of substrate 1; and shows a via 29 disposed through substrate 1 and electrically coupled to trace 30 and patch 24.</u> Electrical trace 30 is preferably configured as a planar transmission line, and more preferably as a microstrip line or a coplanar waveguide line. Instead of microstrip line or coplanar waveguide line,

preferred implementations of trace 30 may be configured as slot-lines, coplanar strips, and symmetrical striplines, as well as other types of planar transmission lines. As is known in the art, a microstrip line comprises a conductive trace disposed on one surface of a substrate layer, and conductive ground plane disposed on the opposite surface of the substrate layer and underlying the conductive trace. A microstrip configuration for the electrical trace 30 is show in FIGS. 1 and 2 where the underlying ground plane is shown at reference number 34 in FIG. 1. A grounded coplanar waveguide line comprises the electrical trace and underlying ground plane of the microstrip structure (*e.g.*, trace 30 and ground plane 34), plus additional ground planes on the top surface of the substrate layer, and disposed on either side of the electrical trace. The additional ground planes are shown in dashed lines at reference numbers 36 and 38 in FIGS. 2 and 3. The additional ground planes 36 and 38 are preferably electrically coupled to the underlying ground plane 34 by a plurality of electrically conductive vias 39. Each location of a via 39 is outlined by dashed circle in FIGS. 1 and 2, and an exemplary one is shown in cross-sectional view by FIG. 3. As seen in FIG. 3 with the reference numbers shown within parentheses, ground planes 34 and 36 are disposed on opposite surfaces of substrate 1, and via 39 is disposed through substrate 1 and between ground planes 34 and 36. In addition, conductive trace 30 and ground planes 34, 36 and 38 may be formed within substrate layer 1 if substrate layer 1 comprises multiple interleaving sub-layers of dielectric material and patterned conductive material.

Please replace the paragraph at page 9, lines 6-19 of the Specification with the following amended paragraph:

As is well known in the art, the ~~follow~~ following factors influence the characteristic impedance of trace 30: the dielectric constant and thickness of substrate layer 1, the strip width of trace 30, and the distance of the gap between trace 30 and each of additional ground planes 36 and 38 (if present). One usually has a desired characteristic impedance in mind (usually 50 ohms), and usually has to work with a given substrate layer thickness and dielectric constant. Therefore, one usually varies the strip width of trace 30 and the gap between it and the top-side ground planes 36 and 38 (if present) to achieve the desired level of characteristic impedance. This selection task has

been well analyzed in the art, and many college-level books on electromagnetic engineering contain tables and charts which related the trace's strip width to the resulting level of characteristic impedance for a number of transmission line structures. Accordingly, the selection of strip width for trace 30 to achieve a desired level of characteristic impedance is within the ordinary skill of the art and no further explanation need be given here for one of ordinary skill in the art to make and use the present invention.

Please replace the paragraph at page 9, line 30 through to page 10, line 8 of the Specification with the following amended paragraph:

FIG. 5 shows an embodiment 20' where two capacitive diaphragms 28′ and 28″ have been used in place of a single diaphragm 28. Embodiment 20' uses the following components of the embodiment 20 shown in FIGS. 1-4 as previously described: substrate 1 with major surfaces 2 and 3; first area 21; ground ring 22; patch antenna 24 with width W and length L; vias 29; ground plane 34, and vias 39. Embodiment 20' is attached to the same waveguide 10 as shown in FIGS. 1 and 2, with the attachment being illustrated by dashed attachment lines 50. Waveguide 10 has first end 11, second end 12, housing 14, longitudinal dimension 15, walls 16, and lip 18, as previously described. The two diaphragms 28′ and 28″ of embodiment 20' are located on either side of the length of patch antenna 24, and antenna 24 has been shifted more toward the center of the first area defined by ground ring 22. In addition, the position of via 32 has been moved from being outside of the perimeter of patch antenna 24 (as fed to the antenna by a short trace), to being located within the antenna's perimeter. Otherwise, the rest of the components are identically placed. Diaphragm 28′ is identical to diaphragm 28, ~~expect~~ except for a more narrow width and the lack of a rounded removed section to accommodate via 32, and diaphragm 28″ may be a mirror image of diaphragm 28′. The variations described above for diaphragm 28 may be applied to diaphragms 28′ and 28″.

Please replace the paragraph at page 10, line 11 through to page 11, line 4 of the Specification with the following amended paragraph:

The frequency of operation, f_{op}, for coupling structure 20 can be selected by selecting the effective length L_{eff} of the patch antenna. The effective length L_{eff} is slightly larger than the actual length L of the patch, and the increased amount of L_{eff} accounts for the fringing electric fields at the far ends (*i.e.*, distal ends) of the patch. As is well known in the art, the frequency of operation f_{op} has a corresponding free-space wavelength λ_{op}: $\lambda_{op} = c / f_{op}$ where c is the speed of light. For a given value of f_{op}, the effective length L_{eff} is usually selected to be equal to the quantity:

$$\cancel{L_{eff} = \frac{1}{2} \cdot \frac{\lambda_{op}}{\sqrt{\varepsilon_{r,.eff}}},} \quad \underline{L_{eff} = \frac{1}{2} \cdot \frac{\lambda_{op}}{\sqrt{\varepsilon_{r,eff}}}},$$

where $\epsilon_{r,eff}$ is the effective relative dielectric constant of substrate layer 1 as seen by patch antenna 24. (We note that for the purposes of using the above equation, the length dimension is the one where the electrical signal is fed to one side of the dimension, and the width dimension is the one where the electrical signal is fed at the center of the dimension.) The effective relative dielectric constant for the patch antenna is generally approximated by the following formula that is known to the art:

$$\epsilon_{r,eff} = 1 + 0.63 \cdot (\epsilon_r - 1) \cdot \left(\frac{W}{d_S} \right)^{0.1255} \quad \text{for } W > d_S,$$

where ϵ_r is the effective dielectric constant of the material forming substrate 1, where W is the width of the patch antenna, where d_S is the thickness of substrate 1, and where the formula is applicable for the case of $W > d_S$. For the embodiments we are considering, the width W will be much greater than the thickness d_S.

Please replace the paragraph at page 11, lines 5-17 of the Specification with the following amended paragraph:

We now consider the case of computing a value of L_{eff} for an operating frequency

of f_{op} = 76 GHz, a patch width W of approximately 2 mm, a substrate thickness d_S of 0.1 mm, and a relative dielectric constant $\epsilon_r = 3.0$ for substrate 1. From these values, we find that the effective relative dielectric constant $\epsilon_{r,eff} = 2.835$, $\lambda_{op} = 3.945$ mm, and $L_{eff} = 1.171$ mm. We must now determine the extent of the fringing fields in order to compute the actual length L of the patch antenna from L_{eff}. The customary approach in the art for accounting for the fringing fields is to assume that the fringing fields extend a distance of one-half the substrate thickness, that is $0.5 \cdot d_S$, at each distal end (*i.e.*, far end) of the antenna's length, which makes: $L_{eff} \approx L + d_S$, which is equivalent to: $L \approx L_{eff} - d_S$. The true effective extent and effect of the fringing fields can be better estimated by simulation with a ~~3-d~~ 3-D electromagnetic simulator. We have done that, and found that the effective extent of the fringing fields for our constructed embodiment is around $0.675 \cdot d_S$, giving $L \approx L_{eff} - 1.35 \cdot d_S$, and a value of L = 1.171 mm − 0.135 mm = 1.036 mm.

Please replace the paragraph at page 11, line26 through to page 12, line 9 of the Specification with the following amended paragraph:

Once a value of L is selected, impedance matching between the impedance of the planar transmission line and the impedance of the waveguide at the operating frequency f_{op} can be achieved by the selection of the width W of patch antenna 24, and/or the selection of the dimensions of the capacitive diaphragm 28. As is known in the transmission line art, inductive and/or capacitive reactances can be added at the junction of two transmission lines of different characteristic impedances in order to provide a matching of the impedances at a specific operating frequency, and for small frequency range thereabout. If the impedances are not well matched at the specific frequency, a significant portion of the signal 4 transmitted on trace 30 will be reflected back to MMIC 8, leading to a low degree of transmission from MMIC 8 to waveguide 10. A good matching of impedances at the specific frequency is demonstrated by a low amount reflection and a high degree of transmission.